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APPLICATION NUMBER: ***60/636,123***
FILING DATE: ***December 15, 2004***
RELATED PCT APPLICATION NUMBER: ***PCT/US05/15736***

UNITED STATES PATENT AND TRADEMARK OFFICE
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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EV504353355US

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Nadajarah	Narendran	Clifton Park, New York

Additional inventors are being named on the 2 *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max):

HIGH EFFICIENCY LIGHT SOURCE USING SOLID-STATE EMITTER AND DOWN-CONVERSION MATERIAL

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

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Address		
City	State	Zip
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ENCLOSED APPLICATION PARTS ***(check all that apply)***

☐ Application Data Sheet. See 37 CFR 1.76
☑ Specification *Number of Pages* 23
☑ Drawing(s) *Number of Sheets* 20
☐ CD(s), Number of CDs
☐ Other (specify)

Application Size Fee: If the specification and drawings exceed 100 sheets of paper, the application size fee due is $250 ($125 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

METHOD OF PAYMENT OF FILING FEES AND APPLICATION SIZE FEE FOR THIS PROVISIONAL APPLICATION FOR PATENT

☑ Applicant claims small entity status. See 37 CFR 1.27.
☐ A check or money order is enclosed to cover the filing fee and application size fee (if applicable).
☑ Payment by credit card. Form PTO-2038 is attached
☑ The Director is hereby authorized to charge the filing fee and application size fee (if applicable) or credit any overpayment to Deposit Account Number: 08-0350. A duplicative copy of this form is enclosed for fee processing.

TOTAL FEE AMOUNT ($): 100.00

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☐ No.
☑ Yes, the name of the U.S. Government agency and the Government contract number are: DEFC26-OINT41203

SIGNATURE Stanley Weinberg
Date December 15, 2004

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REGISTRATION NO. 25,276
(if appropriate)
Docket Number: RPI-134USP

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USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

PROVISIONAL APPLICATION COVER SHEET
Additional Page

PTO/SB/16 (12-04)
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First Named Inventor	Nadajarah Narendran et al.	Docket Number	RPI-134USP

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Number 2 of 2

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Effective on 12/08/2004.
Fees pursuant to the Consolidated Appropriations Act, 2005 (H.R. 4818).

FEE TRANSMITTAL
For FY 2005

☑ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT	($) 100.00

Complete if Known	
Application Number	To Be Assigned
Filing Date	Herewith
First Named Inventor	Nadajarah Narendran et al.
Examiner Name	To Be Assigned
Art Unit	To Be Assigned
Attorney Docket No.	RPI-134USP

METHOD OF PAYMENT (check all that apply)

☐ Check ☑ Credit Card ☐ Money Order ☐ None ☐ Other (please identify): ____

☑ Deposit Account Deposit Account Number: 18-0350 Deposit Account Name: RatnerPrestia

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FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES

Application Type	FILING FEES Fee ($)	FILING FEES Small Entity Fee ($)	SEARCH FEES Fee ($)	SEARCH FEES Small Entity Fee ($)	EXAMINATION FEES Fee ($)	EXAMINATION FEES Small Entity Fee ($)	Fees Paid ($)
Utility	300	150	500	250	200	100	
Design	200	100	100	50	130	65	
Plant	200	100	300	150	160	80	
Reissue	300	150	500	250	600	300	
Provisional	200	100	0	0	0	0	100

2. EXCESS CLAIM FEES

Fee Description	Fee ($)	Small Entity Fee ($)
Each claim over 20 or, for Reissues, each claim over 20 and more than in the original patent	50	25
Each independent claim over 3 or, for Reissues, each independent claim more than in the original patent	200	100
Multiple dependent claims	360	180

Total Claims ____ - 20 or HP = **Extra Claims** ____ x **Fee ($)** ____ = **Fee Paid ($)** 0

HP = highest number of total claims paid for, if greater than 20

Indep. Claims ____ - 3 or HP = **Extra Claims** ____ x **Fee ($)** ____ = **Fee Paid ($)** 0

HP = highest number of independent claims paid for, if greater than 3

Multiple Dependent Claims **Fee ($)** ____ **Fee Paid ($)** ____

3. APPLICATION SIZE FEE

If the specification and drawings exceed 100 sheets of paper, the application size fee due is $250 ($125 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

Total Sheets 43 - 100 = **Extra Sheets** ____ / 50 = **Number of each additional 50 or fraction thereof** ____ (round up to a whole number) x **Fee ($)** ____ = **Fee Paid ($)** 0

4. OTHER FEE(S) **Fees Paid ($)**

Non-English Specification, $130 fee (no small entity discount) ____

Other: ____ ____

SUBMITTED BY

Signature	Stanley Weinberg	Registration No. (Attorney/Agent)	25,276	Telephone	(610) 407-0700
Name (Print/Type)	Stanley Weinberg			Date	December 15, 2004

CERTIFICATE OF MAILING BY "EXPRESS MAIL" (37 CFR 1.10) Applicant(s):			Docket No. RPI-134USP
Serial No. To Be Assigned	Filing Date Herewith	Examiner To Be Assigned	Group Art Unit To Be Assigned
Invention: HIGH EFFICIENCY LIGHT SOURCE USING SOLID-STATE EMITTER AND DOWN-CONVERSION MATERIAL			

I hereby certify that the following correspondence:

New Provisional Patent Application, Related Papers, and Fees

(Identify type of correspondence)

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P06A/REV02

HIGH EFFICIENCY LIGHT SOURCE USING SOLID-STATE EMITTER AND DOWN-CONVERSION MATERIAL

RELATED APPLICATION

This application claims the benefit of priority to U.S. Provisional Patent Application Serial Number 60/568,373, filed on May 5, 2004, the contents of which are incorporated in this application by reference.

BACKGROUND OF THE INVENTION

Solid state light emitting devices, including solid state lamps including light emitting diodes (LEDs) and resonant cavity LEDs (RCLEDs) are extremely useful because they potentially offer lower fabrication costs and long term durability benefits over conventional incandescent and fluorescent lamps. Due to their long operation (burn) time and low power consumption, solid state light emitting devices frequently provide a functional cost benefit, even when their initial cost is greater than that of conventional lamps. Because large scale semiconductor manufacturing techniques can be used, many solid state lamps can be produced at extremely low cost.

In addition to applications such as indicator lights on home and consumer appliances, audio visual equipment, telecommunication devices and automotive instrument markings, LEDs have found considerable application in indoor and outdoor informational displays.

With the development of efficient LEDs that emit blue or ultraviolet (UV) light, it has become feasible to produce LEDs that generate white light through phosphor conversion of a portion of the primary emission of the LED to longer wavelengths. Conversion of primary emissions of the LED to longer wavelengths is commonly referred to as down-conversion of the primary emission. An unconverted portion of the primary emission combines with the light of longer wavelength to produce white light.

Phosphor conversion of a portion of the primary emission of the LED is attained by placing a phosphor in an epoxy that is used to fill the reflector cup, which

houses the LED within the LED lamp. The phosphor is in the form of a powder that is mixed into the epoxy prior to curing the epoxy. The uncured epoxy slurry containing the phosphor powder is then deposited onto the LED and is subsequently cured.

The phosphor particles within the cured epoxy generally are randomly oriented and interspersed throughout the epoxy. A portion of the primary light emitted by the LED passes through the epoxy without impinging on the phosphor particles, whereas a portion of the primary light emitted by the LED impinges on the phosphor particles, thereby causing the phosphor particles to emit complimentary light. The combination of the primary blue light and the phosphor-emitted light produces white light.

Current state of the art LED technology is inefficient in the visible spectra. The light output for a single LED is below that of known incandescent lamps, which are approximately 10 percent efficient in the visible spectra. An LED device having a comparable light output power density necessitates a larger LED design or a design comprising a multiple LED configuration. Moreover, a form of direct energy absorbing cooling must be incorporated to handle the temperature rise in the LED device itself. More particularly, the LED device becomes less efficient when heated to a temperature greater than 100°C., thus creating a declining return in the visible spectra. The intrinsic phosphor conversion efficiency therefore drops dramatically as the temperature increases above an approximately 90°C threshold.

U.S. Patent No. 6,452,217 issued to Wojnarowski et al. is directed to a high power LED lamp or multiple LED lamp design for use in lighting products and a source of heat removal therefrom. It has LED die arranged in a multi-dimensional array. Each LED die has a semiconductor layer and phosphor material for creation of white light. A reflector gathers and focuses the light from each of the die to approximate a high power LED lamp. Fig. 12 illustrates a multi-sided array which emits light at angled ray trace paths. Fig. 19 illustrates the LED lamp head being angled.

U.S. Patent No. 6,600,175 issued to Baretz et al. and U.S. Patent Application Publication No. 2004/0016938 filed by Baretz et al. are directed to solid state light emitting devices that produce white light. The '938 patent application

publication is a continuation of the '175 patent. The solid state light emitting device generates a shorter wavelength radiation that is transmitted to a luminophor for down conversion to yield white light. In Figures 2 and 6, there is a spaced relationship between the LED and the luminophoric medium. In Figure 6, for example, light is emitted from the solid state device 82 of shorter wavelength radiation, preferably in the wavelength range of blue to ultraviolet. When luminophoric medium 90 is impinged with the shorter wavelength radiation, it is excited to responsively emit radiation having a wavelength in the visible light spectrum in a range of wavelengths to produce light perceived as white.

U.S. Patent No. 6,630,691 issued to Mueller-Mach et al. is directed to an LED device comprising a phosphor-converting substrate that converts a fraction of the primary light emitted by a light emitting structure of the LED into one or more other wavelengths of light that combine with unconverted primary light to produce white light. As shown in Fig. 1, the LED 2 is disposed on a substrate 10 which is a phosphor. As shown in Fig. 2, a reflective electrode 21 is disposed on the surface of the LED. Some primary light emitted by the LED impinges on the reflective electrode 21 which reflects the primary light back through the LED and through the substrate. Some of the primary light propagating into the substrate is converted into yellow light and some is not. When the two types of light are emitted by the substrate, they combine to produce white light. Utilizing a reflective electrode improves the efficiency of the LED device by ensuring that the amount of primary light entering the substrate is maximized.

U.S. Patent Application Publication No. 2002/0030444 filed by Muller-Mach et al., which issued as U.S. Patent No. 6,696,703 to Mueller-Mach et al. are directed to a thin film phosphor-converted LED structure. Fig. 2 shows an LED structure 2 and a phosphor thin film 21 on a surface of LED 2. The LED generates blue light that impinges on phosphor film 21. Some light passes through phosphor 21 and some is absorbed and converted into yellow light which is emitted from phosphor 21. The blue and yellow light combine to form white light. In Fig. 3, a reflective pad 25 is on a surface of the LED 2. Light from LED 2 is reflected by reflective pad 25 back through LED 2 and into phosphor 21. Light is then combined as in Fig. 2. Fig. 4 uses two phosphor films 31, 33 that are separated from LED 2 by substrate 13. Film 31 emits red light. Film 33 emits green light. Blue light emitted by LED 2 passes through

films 31, 33 which combines with the red and green light to produce white light. In the embodiment of Fig. 5, the LED device 50 includes a plurality of phosphor thin films 37 and 38. A dielectric mirror 36 is disposed between thin film 37 and the substrate 13. The dielectric mirror 36 is fully transparent to the primary emission of the light emitting structure 2 but is highly reflective at the wavelength of the emissions of the phosphor thin films 37 and 38.

U.S. Patent Application Publication No. 2002/0030060 filed by Okazaki is directed to a white semiconductor light-emitting device provided with an ultraviolet light-emitting element and a phosphor. The phosphor layer has a blue light-emitting phosphor and a yellow light-emitting phosphor mixedly diffused. The light-emitting device 3 is inside a reflective case 5. In Figures 2, 4, and 8, a phosphor layer 6 is formed away from the light-emitting element 3. In Fig. 2, the phosphor layer 6 is formed inside a sealing member 7 formed out of a translucent resin. In Figures 4 and 8, the phosphor layer is formed on the surface of the sealing member 7.

U.S. Patent Application Publication No. 2002/0218880 filed by Brukilacchio is directed to an LED white light optical system. As shown in Fig. 1, the optical system 100 includes an LED optical source 110, an optical filter 120, a reflector 130, a phosphor layer 135, a concentrator 140, a first illumination region 150, a second illumination region 170, and a thermal dissipater 190. Optical filter 120 includes a reflected CCT range and a transmitted CCT range. Optical energy that is within the reflected CCT range is prohibited from passing through the optical filter 120 (e.g., via reflection). Optical energy that enters the optical filter front face 121 from the phosphor layer back face 137 that is in the reflected range of the optical filter 120 will be reflected back into the phosphor layer 135. Optical energy that is in the transmitted CCT range of the optical filter 120 will transmit through filter 120 and interacts with reflector 130.

The reflector 130 is a reflective optical element positioned to reflect optical energy emitted from the LED optical source back face 112 back into the LED optical source 110. The optical energy interacts with the optical material and a portion of the optical energy will exit LED front face 111 and interact with the optical filter 120. It then continues into the phosphor layer thereby providing a repeating telescoping circular process for the optical energy that emits out of the phosphor layer

back face 137. This repeating process captures optical energy that would otherwise be lost. Concentrator 140 captures optical energy emitting out of the phosphor layer front face 136.

U.S. Patent Application Publication No. 2002/0003233 filed by Mueller-Mach et al., which issued as U.S. Patent No. 6,501,102 to Mueller-Mach et al., are directed to a LED device that performs phosphor conversion on substantially all of the primary radiation emitted by the light emitting structure of the LED device to produce white light. The LED device comprises at least one phosphor-converting element located to receive and absorb substantially all of the primary light emitted by the light-emitting structure. The phosphor-converting element emits secondary light at second and third wavelengths that combine to produce white light. Some embodiments use a reflective electrode on the surface of the light emitting structure and some do not. In embodiments that use a reflective electrode 21 (Figs. 2, 3, 6, 7), a substrate separates the light emitting structure from the phosphor layers. That is, the light emitting structure is on one side of the substrate and a phosphor is on the other side of the substrate. In embodiments that do not use a reflective electrode (Figs. 4, 5), a phosphor layer is disposed on a surface of the light emitting structure.

U.S. Patent No. 6,686,691 issued to Mueller et al. is directed to a tri-color lamp for the production of white light. The lamp employs a blue LED and a mixture of red and green phosphors for the production of white light. As shown in Fig. 3, lamp 20 comprises LED 22 which is positioned in a reflector cup 28. LED 22 emits light in a pattern indicated by lines 26 and a phosphor mixture 24 is positioned in the pattern 26. It can be seen that some unabsorbed light emitted by LED 22 can reflect from walls of reflector cup 28 and back to phosphor mixture 24. Reflector cup 28 can modify light pattern 26 if light is reflected into a space not previously covered by the initial light pattern. The walls of the reflector cup may be parabolic.

U.S. Patent No. 6,252,254 and 6,580,097, both issued to Soules et al., are directed to an LED or laser diode coated with phosphors. The '097 patent is a division of the '254 patent. More particularly, the patents comprise a blue-emitting LED covered with a phosphor-containing covering. The phosphor-containing covering contains green-emitting phosphors and red-emitting phosphors. The green and red phosphors are excitable by the blue-emitting LED.

U.S. Patent No. 6,513,949 issued to Marshall et al., U.S. Patent No. 6,692,136 issued to Marshall et al., and U.S. Patent Application Publication No. 2002/0067773 filed by Marshall et al. are directed to an LED/phosphor/LED hybrid lighting system. The '136 patent is a continuation of the '949 patent. The '773 patent application publication issued as the '136 patent. As shown in Fig. 1A, the LED 10 is conventionally constructed and comprises an LED chip mounted in a reflective metal dish or reflector 12 filled with a transparent epoxy 13. Fig. 1B schematically depicts a typical phosphor-LED 14 which is substantially identical in construction to the LED of Fig. 1A, except that the epoxy 18 filling the reflector 16 contains grains 19 of one or more types of luminescent phosphor materials mixed homogeneously therein. The phosphor grains 19 convert a portion of the light emitted by the LED chip 15 to light of a different spectral wavelength. The system permits different lighting system performance parameters to be addressed and optimized as deemed important by varying the color and number of the LEDs and/or the phosphor of the phosphor-LED.

U.S. Patent No. 6,603,258 issued to Mueller-Mach et al. is directed to a light emitting diode device that produces white light by combining primary bluish-green light with phosphor-converted reddish light. The LED is mounted within a reflector cup that is filled with a phosphor-converting resin. Primary radiation emitted by the LED impinges on the phosphor-converting resin. Part of the primary radiation impinging on the resin is converted into reddish light. An unconverted portion of the primary radiation passes through the resin and combines with the reddish light to produce white light.

U.S. Patent No. 6,616,862 issued to Srivastava et al. is directed to halophosphate luminescent materials co-activated with europium and manganese ions. Figure 3 discloses an LED mounted in a cup 120 having a reflective surface 140 adjacent the LED. The embodiment includes a transparent case 160 in which phosphor particles 200 are dispersed. Alternatively, the phosphor mixed with a binder may be applied as a coating over the LED surface. A portion of blue light emitted by the LED that is not absorbed by the phosphor and the broad-spectrum light emitted by the phosphor are combined to provide a white light source.

U.S. Patent Nos. 6,069,440, 6,614,179, and 6,608,332 issued to Shimazu et al. are directed to a light emitting device comprising a phosphor which

converts the wavelength of light emitted by a light emitting component and emits light. These patents also disclose a display device using multiple light emitting devices arranged in a matrix. These patents are all related in that they flow from the same parent application.

U.S. Patent No. 6,580,224 issued to Ishii et al. is directed to a backlight for a color liquid crystal display device, a color liquid crystal display device, and an electroluminescent element for a backlight of a color liquid crystal display device.

U.S. Patent Application Publication No. 2002/0167014 filed by Schlereth et al., which issued as U.S. Patent No. 6,734,467 to Schlereth et al., are directed to an LED white light source having a semiconductor LED based on GaN or InGaN which is at least partly surrounded by an encapsulation made of a transparent material. The transparent material contains a converter substance for at least partial wavelength conversion of the light emitted by the LED. The LED has a plurality of light-emitting zones by which a relatively broadband light emission spectrum is generated energetically above the emission spectrum of the converter substance.

A publication entitled "Optical simulation of light source devices composed of blue LEDs and YAG phosphor" by Yamada K., Y. Imai, and K Ishii published in Journal of Light and Visual Environment 27(2): 70-74 (2003).

DETAILED DESCRIPTION OF THE INVENTION

Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

The inventors have discovered that the performance of phosphor converted LEDs is negatively affected by placing the down-conversion phosphor close to the LED die. Poor performance is mainly due to the fact that the phosphor medium surrounding the die behaves like an isotropic scatterer, and some portion of the light that reflects back from the die circulates between the phosphor layer, the die, and the reflector cup. As a result, the light coupled back into the device increases the junction

temperature, thus reducing system efficacy and increasing the yellowing of the encapsulant. All of these factors reduce the light output over time.

The literature shows that 60 percent of the light impinging on the phosphor layer is reflected back, contributing to the described effects (Yamada, et al., 2003). Lab measurements of eight YAG:Ce phosphor plates proved that nearly 60% of the radiant energy is reflected back in the direction of the blue LED source. The absolute magnitude of the radiant energy reflected depends, among other factors, on the density of the phosphor coating. Figure 1 shows the measured reflected spectral power distribution 2 of a blue LED with a YAG:Ce phosphor plate. Figure 1 also shows the measured transmitted spectral power distribution 4 of the same arrangement. Such effects are expected to be of a higher magnitude in RCLEDs because their light output is much more collimated. Therefore, the packaging captures both the transmitted and reflected components to improve system efficiency. Additionally, the inventors have created packaging that allows the phosphor layer to be moved away from the die, preventing light feedback into the LED and RCLED. As a result, the life of the LED and RCLED can be improved. At the same time, light from the RCLED impinges on the phosphor layer uniformly to obtain a uniform white light source. In addition, the packaging increases the efficiency of the device by allowing more of the light reflected off the phosphor layer to exit.

Figure 2 illustrates a first embodiment of the invention having distributing optic, light transmissive, enclosure optic 10. In an exemplary embodiment of the first embodiment, enclosure optic 10 has a phosphor layer 12 embedded in the middle section of the distributing optic, as if splitting the distribu ting optic into substantially two equal pieces. That is, the phosphor layer may be substantially parallel to a longitudinal axis of the enclosure optic 10 and the middle section may also be substantially parallel to the longitudinal axis of the optic. In an exemplary embodiment, the phosphor layer may be a YAG:Ce phosphor layer. In an alternative embodiment, the phosphor layer may comprise other phosphors, quantum dots, quantum dot crystals, quantum dot nano crystals or other down conversion material. In all of the embodiments disclosed in this application the phosphor may be a YAG:Ce layer, other phosphors, quantum dots, quantum dot crystals, quantum dot nano crystals, or other down conversion material. In addition, although the exemplary first embodiment may use an embedded phosphor layer, in an alternative first

embodiment, the phosphor layer need not be embedded. An LED or RCLED 14 may be placed inside at the bottom of the distributing optic. In an alternative first embodiment, LED/RCLED 14 may be placed at a location other than at the bottom of the distribution optics. In another alternative embodiment of the first embodiment, an LED/RCLED may be placed at both ends of the optical element.

Short wavelength light 16 is emitted from LED/RCLED 14. Short wavelength light is in the range of 250 nm to 500 nm. Because phosphor layer 12 is substantially in the middle of the enclosure optic 10, it may also be substantially in the middle of LED/RCLED 14. Consequently, short-wavelength light from LED/RCLED 14 causes short-wavelength light to impinge from either side of phosphor layer 12 onto the phosphor layer. The impingement of short-wavelength light onto the phosphor layer produces light with four components: short-wavelength light 18 reflected from the phosphor layer; short-wavelength light 20 transmitted through the phosphor layer; down-converted light 22 reflected from the phosphor layer; and down-converted light 24 transmitted through the phosphor layer. These four components are produced on both sides of the phosphor layer, combine, and produce white light 26. That is, this process takes place from both sides of the phosphor layer. As a result, the total light extraction is increased.

The light (short-wavelength and down-converted light) that otherwise would be reflected back into the die, if the die was embedded in the phosphor layer, is transmitted to the exterior of the distributing optic through the light transmissive enclosure optic 10. In an exemplary embodiment of the first embodiment, a high-flux blue (470nm) illuminator LED (Shark series) by Opto Technology may be used. The density of the phosphor layer 12 may be in the range of 4-8 mg/cm^2 the length of the enclosure optic 10 may be in the range of 2 to 4 inches, and the diameter of the enclosure optic 10 may be 0.5 inches. In an alternative embodiment of the first embodiment, a different design in terms of package efficiency and uniformity may be achieved by changing the phosphor-layer density and the length and diameter of the enclosure optic 10. For example, better efficiency and uniformity at the receiver may be achieved when the distributing optic is 2.25 inches long.

Phosphor density may be any other densities. Half-round acrylic rod segments may be cut to size and polished. Phosphor may be mixed with optically

clear epoxy and spread uniformly on the flat surface of a rod. The rod may be attached to another clean rod and put into an oven to cure the epoxy.

The overall loss for a 2.25 inch optical element was found to be approximately 16%. The losses included:

- 6% light reflected back to the LED
- 7% Fresnel loss
- 3% irrecoverable loss due to mounting hardware

Approximately half of the losses may be attributed to the Fresnel loss, which occurs at the boundaries between media with different refractive indices. Fresnel losses may be reduced by using a coupling mechanism between the LED/RCLED 14 and the enclosure optic 10. In addition, losses may be recovered by using an anti-reflective coating on the LED source to prevent light from reflecting back to the LED.

Figures 3 and 3A illustrate a second embodiment of the invention having distributing optic, light transmissive, enclosure optic 30. Figure 3A is a top view of the embodiment shown in Figure 3. In an exemplary embodiment of the second embodiment, enclosure 30 may be cylindrical and may be made of glass or acrylic that is light transmissive. In an alternative embodiment of the second embodiment, the enclosure may be in the shape of an ellipse or a square. An LED or RCLED 34 may be placed inside and at the bottom of the distributing optic. In an alternative embodiment of the first embodiment, an LED/RCLED may be placed at both ends of the optical element. A phosphor layer 32 may be embedded into an arc section of the distributing optic. That is, the phosphor layer 32 may be embedded in, and substantially parallel to, a longitudinal axis of the enclosure optic 30. In an exemplary embodiment of the second embodiment, the arc length of phosphor layer may be in a range of 30 degrees to 100 degrees.

In an exemplary embodiment, the phosphor layer may be a YAG:Ce phosphor layer. In an alternative embodiment, the phosphor layer may be any other down conversion material that has characteristics similar to YAG:Ce. In addition,

although the exemplary second embodiment may use an embedded phosphor layer, in an alternative second embodiment, the down conversion material layer need not be embedded. Instead, it may be coated outside optic 30. Although the bottom of the phosphor layer may contact the LED/RCLED, the remainder of the phosphor layer is away from the LED/RCLED.

A mirror or other reflective surface 33 (for example, a specular surface) may be placed behind the phosphor layer 32 and also embedded in the distribution optics. In an alternative embodiment, the reflective surface may be coated outside the phosphor layer or optics. In an exemplary embodiment of the second embodiment, the arc length of mirror 33 may be substantially equal to the arc length of phosphor layer 32 and may be in the range of 30 degrees to 100 degrees. In an exemplary embodiment of the second embodiment, mirror 33 may be in direct physical contact with phosphor layer 32 along the entire length of the phosphor layer.

The enclosure optic 30 may receive light from the LED/RCLED 34 and redirect it to the phosphor layer 32 embedded in the distribution optics. Mirror 33 may direct the light transmitted through the phosphor layer back into the distribution optics. The redirected light in the distribution optics 30 contributes to the total light output of the device. More specifically, short wavelength light 36 is emitted from LED/RCLED 34. Short-wavelength light 38 is reflected from the phosphor layer back into the distribution optics; and reflected down-converted light 42 is reflected from the mirror back through the phosphor layer and into the distribution optics. These light components combine (with the other components described above regarding the first embodiment, but not illustrated in Figures 3 and 3A) to produce white light 46.

The phosphor-layer density, arc length of phosphor layer or mirror, and the length and diameter of the optics control the uniformity of the light, beam distribution, and the efficiency of the device. In an exemplary embodiment of the second embodiment, the phosphor-layer density may be in the range of 4 to 8 mg/cm^2. In an exemplary embodiment of the second embodiment, the length of the optics may be in the range of 2 to 4 inches and the diameter of the optics may be 0.5 inch.

In an exemplary embodiment of the second embodiment, the diameter of the optics may be 0.5 inch. The length of the phosphor rod may be in the range of 2 inches to 6 inches. The overall loss for a 5 inch optical element was approximately 22%. The losses included:

- 6% light reflected back to the LED
- 5% Fresnel loss
- 11% irrecoverable loss due to mounting hardware

The efficiency may be increased by using a coupling mechanism such as an anti-reflective coating on the LED source.

Figure 4 illustrates a third embodiment of the invention. This embodiment may be used in interior spaces where general ambient lighting is required. The package includes a phosphor plate 50 comprising, in an exemplary embodiment, YAG:Ce. In an alternative embodiment of the third embodiment, phosphor plate 50 may comprise other phosphors, quantum dots, quantum dot crystals, quantum dot nano-crystals, or other down conversion material. The package also comprises an LED/RCLED array 52. The array 52 is mounted on a substrate 54 that may comprise an aluminum material. In an exemplary embodiment, the substrate may be circular. In other embodiments, the substrate may take whatever shape is required. The array may comprise a plurality of LEDs 56. The array may also comprise a plurality of RCLEDs or may comprise a combination of LEDs and RCLEDs. In the exemplary configuration illustrated in Figure 4, the LEDs are arranged in a spaced relation around the circular substrate. If a different shape substrate is used, the LEDs may be placed in a different configuration on the substrate.

The array of LEDs are placed on the substrate so that the light emitting surfaces of the LEDs face toward the phosphor layer plate 50 so that they emit short wavelength light toward the phosphor layer plate 50. As the short wavelength light impinges on the phosphor layer plate, four components of light results: short wavelength light and down-converted light 60 and transmitted short wavelength light and transmitted down converted light 64. The short wavelength light and down converted light 60 is reflected into the upper space to produce white light 62. The

transmitted short wavelength light and down-converted light 64 components also combine to produce white light 66.

Figures 5A and 5B illustrate a fourth embodiment of the invention. This embodiment may produce directional light distribution. It includes a cup 500 having an LED 501, reflective walls 502 and phosphor layers 504 and 506. Phosphor layer 504 is away from LED 501. Phosphor layer 506 is bonded to the inside of reflective walls 502.

Figures 5C and 5D are modifications of the embodiment shown in Figures 5A and 5B. In Figures 5C and 5D, the mirror has been removed.

The embodiment shown in Figures 5C and 5D may be used in interior spaces where general ambient lighting is required. The package includes a transparent cup having an LED/RCLED or an LED/RCLED array and phosphor layers. One phosphor layer is bonded to the inside transparent wall of the cup. And the other phosphor layer is bonded to only the center area of the front. Thus most of the reflected short wavelength light and down-converted light on the side wall can exit from the transparent part of the front surface directly. Narrow beam LED/RCLED is preferred in this embodiment to prevent too much short wavelength light from the LED/RCLED directly exits the transparent part of the front surface without hitting the phosphor layer. The cup may be glass or acrylic.

Figure 6 illustrates a fifth embodiment 600 of the invention. This embodiment comprises an LED 602 separated from a phosphor layer 604 by a transparent medium 606. In an exemplary embodiment, the transparent medium 606 may be air. In an alternative embodiment, transparent medium 606 may be glass or acrylic. Phosphor 604 may be mounted on a lens 608 having transparent walls 610, 612.

Figure 7 illustrates a sixth embodiment of the invention. In this embodiment, embodiment 600 is disposed within a reflector 702. In an exemplary embodiment, reflector 702 may have the shape of a parabola. In an alternative embodiment, reflector 702 may have the shape of a cone. The advantages of this package are to control the beam distribution and to achieve uniform color. Figures

7A-7F are color photographs of demonstrations for the embodiment illustrated in Figure 7.

Figure 9 illustrates an array 900 comprising a plurality of LED placements 910, 920, 930. Although Figure 9 shows three LED placements, alternative embodiments may comprise more or fewer than three LED placements. Although Figure 9 shows a linear arrangement of LED placements, alternative embodiments may comprise one or more two dimensional arrays of LED placements. Each LED placement 910 may comprise an LED 902, a lens 904, and a reflector 906 surrounding the LED/lens combination. Spaced away from LED 902 may be a linear lightpipe 912 disposed across from the LEDs. Side 914 of lightpipe 912 is adapted to receive light from each of the LED placements. Side 916 of lightpipe 912 includes a phosphor layer 918 facing LED 902 and a microlens layer 920 bonded to the other side of the phosphor layer.

Figure 9A illustrates a two dimensional array 950 of LEDS placements. In Figure 9A, the LEDs are placed on top of a lightpipe 960.

Figure 10 illustrates an alternative location of an LED placement. In Figure 10, LED placement 1000 includes a lightpipe 1002 having an end 1004, a top 1006, and a bottom 1008. On the outside of top 1006 is bonded a phosphor layer 1010 with a microlens 1012 bonded to the phosphor layer. On the outside of bottom 1008, a phosphor layer 1014 and a microlens 1016 are also bonded. Adjacent end 1004 is an LED placement 1018 comprising an LED 1020, a lens 102, and a surrounding reflector 1024.

Figure 10A illustrates an array of LED placements around the edge of a lightpipe. For example, Figure 10A includes LED placements 1020, 1022, 1024, and 1026 placed around the edge of lightpipe 1030.

Figure 11 illustrates an additional embodiment of the invention. Figure 11 shows an LED 1100. A lens 1102 may be mounted on top of the LED. A phosphor layer 1104 is mounted onto the top of lens 1102 so that the phosphor layer is away from the LED and so that a transparent medium is between the phosphor layer and the LED. The LED/lens/phosphor package is surrounded by a reflector 1106 having a high-reflectance. In an exemplary embodiment the measured reflectance may be in

the range of 90 to 97% A high efficiency microlens diffuser 1108 may be placed across the top of reflector 1106. In an exemplary embodiment, the microlens diffuser may exhibit greater than 95% efficiency. In this embodiment, the LED 1100 is disposed between the phosphor layer 1104 and the reflector 1106.

Figure 12 illustrates yet another embodiment of the invention. Figure 12 shows an LED 1200. A phosphor layer 1202 is disposed away from the LED 1200. A transparent medium 1204 may be between LED 1200 and phosphor layer 1202. In an exemplary embodiment, the phosphor layer 1202 may be in the shape of a parabola or other curved shape. A reflector 1206 may be spaced away from the phosphor layer and the LED. A transparent medium 1208 may be between the phosphor layer and the reflector. In this embodiment, the phosphor layer 1202 is disposed between the LED 1200 and the reflector 1206.

Improving efficiency of white light-emitting diodes by recovering phosphor-scattered photons.

Although it is well known that the phosphor used in white light-emitting diodes (LEDs) backscatters more than half the light emitted, which then is eventually lost within the package, no one to date has shown that these photons can be recovered to increase the overall efficacy of the white LED. This application describes and experimentally verifies a scattered photon recovery (SPR) method that significantly increases the overall efficacy of a white LED. At low currents, the SPR package showed over 80 1m/W white light with chromaticity values very close to the blackbody locus.

Developing high-efficiency white light-emitting diodes (LED) has been a topic of interest for several years. Of the different methods available for creating white light, the phosphor-converted emission method is the most common. The first phosphor-converted white LED was introduced during the mid-1990s when cerium doped yttrium aluminum garnet (YAG:Ce) phosphor was combined with a gallium nitride (GaN) based blue LED. In a typical commercial white LED package, the phosphor is embedded inside an epoxy resin that surrounds the LED die. Some portion of the short-wavelength radiation emitted by the GaN LED is down-converted by the phosphor, and the combined light is perceived as white by the human eye.

Although these products proved the white LED concept and have been used in certain niche illumination applications, they are not suited for general lighting applications because of their low overall light output and low efficacy.

To achieve higher luminous efficacy with white LEDs, improvements are needed at several stages: internal quantum efficiency, extraction efficiency, and phosphor-conversion efficiency. Some researchers have taken on the challenge of researching the materials and growth aspects of the semiconductor to improve internal quantum efficiency. Others are exploring shaped chips, photonic crystals, micron-scale LEDs, and other novel methods to improve light extraction efficiency. Still others are investigating new phosphors that have greater down-conversion efficiencies and better optical properties.

Although past literature acknowledges that a significant portion of the light is backscattered by the phosphor and lost within the LED due to absorption, to the best of our knowledge no one to date has attempted to improve performance by extracting these backscattered photons. This application describes a method, referred to as the scattered photon recovery (SPR) method, that significantly increases the overall light output and luminous efficacy of a phosphor-converted white LED by recovering the scattered photons.

To better understand the interaction between primary short-wavelength light and phosphor and to quantify the amount of forward and backward scattered light, several circular glass plates, 5 cm in diameter, were coated with different densities of YAG:Ce phosphor ranging from 2 mg/cm^2 to 8 mg/cm^2. These phosphor plates were placed between two side-by-side integrating spheres with the phosphor coating facing the right sphere (Figure 13). The phosphor material was excited by radiation from a 5 mm blue LED placed inside the right sphere 2.5 cm away from the glass plate. A spectrometer measured the light output from each sphere through the measurement ports. Light output measured from the left and right spheres indicated the amount of light transmitted through and reflected off the phosphor layer, respectively. The spectrometer data was analyzed to determine the amount of flux in the blue and yellow regions, corresponding to the radiant energy emitted by the LED and the converted energy from the YAG:Ce phosphor. Figure 14 presents sample data for one phosphor plate, 7 mg/cm^2. Here, the spectral power distributions for the

transmitted and reflected radiations are different, especially the amount of blue-to-yellow ratio. The amount of transmitted and reflected radiations depends on the phosphor density, with lower densities resulting in higher percentages of transmitted radiation. Typically, the phosphor density is controlled such that the transmitted blue and yellow light are in the correct proportion to produce white light of a suitable chromaticity, which typically places it on or close to the blackbody locus. From the gathered data, it was estimated that about 40% of the light is transmitted when creating a balanced white light, and the remaining 60% is reflected. Yamada et al. found similar results, as reported in K. Yamada, Y. Imai, K. Ishii, J. Light & Vis. Env. 27(2), 70 (2003). In a commercial white LED, a significant portion of this reflected light is absorbed by the components surrounding the die, one of the reasons for its low luminous efficacy.

The next step in this study was to design a method by which most of the reflected light can be recovered. Figure 15 illustrates an LED package with scattered photon recovery (SPR) implemented. Unlike the typical commercial white LED package where the phosphor is spread around the die, in the SPR package the phosphor layer is moved away from the die, leaving a transparent medium between the die and the phosphor. The optimum shape for the package was determined via ray tracing analysis. The geometry of the package plays an important role; it is designed to efficiently transfer the light exiting the GaN die to the phosphor layer and allow most of the backscattered light from the phosphor layer to escape the optic. Compared with the typical commercial package, more photons are recovered with the SPR package. Here again the phosphor density determines the chromaticity of the final white light. It is worth noting that the SPR package requires a different phosphor density to create white light with chromaticity coordinates similar to the traditional white LED package. This difference is a result of the SPR package mixing transmitted and back-reflected light with dissimilar spectra, whereas the traditional package uses predominantly the transmitted light.

To verify the hypothesis that the SPR package provides higher light output and luminous efficacy, an experimental study was carried out with twelve commercial high-flux LEDs, six 3 W blue and six 3 W white, obtained from the same manufacturer. A commercial optic that fit the profile requirements of the SPR package was found, and several were acquired for experimentation with the LEDs. Although

this optical element did not have the optimum geometry to extract all of the backscattered light, it was sufficient to verify the hypothesis. The top flat portion of this secondary optic was coated with a predetermined amount of YAG:Ce phosphor. The required phosphor density was determined in a separate experiment by systematically varying the amount of phosphor density, analyzing the resulting chromaticity, and selecting the density that produced a chromaticity very close to that of the commercial white LED used in this study. To compare the performances of the two packaging concepts, the white LEDs were fitted with uncoated secondary optics. The light output and the spectrum of the commercial white LEDs were measured in an integrating sphere, and the current and the voltage required to power the LEDs were also noted. The same measurements were repeated for the SPR packages, which consisted of blue LEDs fitted with phosphor-coated secondary optics.

Figure 16A is a table that shows the results for all twelve white LED packages, typical and SPR, at equal power use. The average luminous flux and the corresponding average efficacy for the SPR LED packages are 90.7 lm and 36.3 lm/W, respectively. The average luminous flux and the corresponding average efficacy for the typical white LED packages are 56.5 lm and 22.6 lm/W, respectively. Therefore, the SPR LED packages on average have 61% more light output and 61% higher luminous efficacy. The variation of luminous flux and corresponding efficacy between similar LEDs was small, with a standard deviation of less than 4%. The SPR packages consistently had higher lumen output and higher efficacy compared with the typical white LED packages, thus verifying the hypothesis.

To study the impact of current on light output and efficacy, two LED packages from the above twelve, one typical white LED and one SPR package, were selected. These two LEDs were subjected to the same light output measurement procedure, but their input current was decreased from 700 mA to 50 mA in several steps, and the corresponding photometric and electrical data were gathered. Figure 17 illustrates the light output and efficacy of these two LED packages as a function of current. At very low currents, the SPR package exceeds 80 lm/W, compared to 54 lm/W for the traditional package.

With SPR, the backscattered photons are extracted before they are absorbed by the components within the LED. To realize the maximum potential of this

method, it is essential that the phosphor layer be placed farther away from the die, and the backscattered photons must be extracted before they undergo multiple reflections within the package. Moving the phosphor away from the die has an additional benefit: the life of the white LED can also be improved, as demonstrated in an earlier paper (Narendran, N., Y. Gu, J.P. Freyssinier, H. Yu, and L. Deng. 2004. Solid-state lighting: Failure analysis of white LEDs. Journal of Crystal Growth 268 (3-4): 449-456). An alternate method to recover some portion of the backscattered light is to coat the sides of the secondary optics with a reflective material. Although the efficacy may improve compared to a traditional white LED package, the gain will not be as much because the backscattered light will bounce back and forth between the phosphor layer and the reflectors, and a good portion of this light will be absorbed and lost as heat. A drawback to this method is that by increasing the path length of the short-wavelength light traveling through the surrounding epoxy material, the epoxy degrades faster and thus shortens the useful life of the white LED. However, it should be pointed out that the geometry of the SPR package presented in this application is not limited to this specific shape. Alternate shapes could be developed to recover the backscattered photons efficiently while addressing other design concerns, such as color and life.

In summary, it has been demonstrated that by recovering the backscattered light from the phosphor layer, the overall light output and the corresponding luminous efficacy of a white LED can increase significantly compared to a typical white LED. At low currents, the SPR implemented LED package showed over 80 lm/W white light with a chromaticity very close to the blackbody locus. Since the SPR method further improves the overall efficiency, it adds significant hope to white LEDs exceeding 100 lm/W in the near future.

This work was conducted as part of a research grant from the U.S. Department of Energy (DEFC26-OINT41203).

What is claimed:

1. A light emitting device for emitting white light comprising:

a closed distributing optic comprising a light transmissive material;

a light radiation source disposed within the optic;

a down conversion material disposed within the optic along substantially a middle section of the optic.

2. The light emitting device of claim 1, wherein the light radiation source is a light emitting diode.

3. The light emitting device of claim 1, wherein the light radiation source is a resonant cavity light emitting diode.

4. The light emitting device of claim 1, wherein the light radiation source is disposed at one end of the optic.

5. The light emitting device of claim 1, wherein the light radiation source comprises first and second radiation sources disposed at respective ends of the optic.

6. The light emitting device of claim 1, wherein the down conversion material is a phosphorous material.

7. The light emitting device of claim 1, wherein the down conversion material is a phosphor layer disposed substantially parallel to a longitudinal axis of the optic.

8. The light emitting device of claim 1, wherein the middle section of the optic is substantially parallel to a longitudinal axis of the optic.

9. The light emitting device of claim 1, wherein the down conversion material is a YAG:Ce phosphor layer embedded in the optic.

10. The light emitting device of claim 1, wherein the down conversion material is a down-converting phosphor.

11. The light emitting device of claim 1, wherein the light radiation source is adapted to produce light in the range of 250 nm to 500 nm.

12. The light emitting device of claim 1, wherein the down conversion material has luminescent properties on at least two sides of the material and the light radiation source is adapted to produce light on each side of the down conversion material.

13. A lighting device for producing white light comprising:

a closed distributing optic comprising a light transmissive material;

a light radiation source disposed within the optic;

a down conversion material embedded in an arc section of the optic; and

a reflector surface disposed behind the down conversion material.

14. The lighting device of claim 13, wherein the light radiatio n source is a light emitting diode.

15. The lighting device of claim 13, wherein the light radiation source is a resonant cavity light emitting diode.

16. The lighting device of claim 13, wherein the light radiation source is disposed at on end of the optic.

17. The light emitting device of claim 13, wherein the light radiation source comprises first and second radiation sources disposed at respective ends of the optic.

18. The light emitting device of claim 13, wherein the down conversion material is a phosphorous material.

19. The light emitting device of claim 13, where the down conversion material is a phosphor layer disposed in an arc section of the optic.

20. The light emitting device of claim 13, wherein the reflector surface is a diffused surface.

21. The light emitting device of claim 13, wherein the reflector surface is a specular surface.

22. The light emitting device of claim 13, wherein the reflector surface is a mirror.

23. The light emitting device of claim 13, wherein the down conversion material is a phosphor layer disposed in an arc section of the optic, the reflector surface is a mirror, and the mirror is disposed between a wall of the optic and the phosphor layer.

24. The light emitting device of claim 13, wherein the down conversion material is a YAG:Ce phosphor layer embedded in the optic.

25. The light emitting device of claim 13, wherein the light radiation device is adapted to produce light in the range of 250 nm to 500 nm.

26. A lighting device for produce white light comprising:

a substrate;

a plurality of solid state light radiation devices mounted on a side of the substrate; and

a layer of down conversion material adjacent the side of the substrate on which the plurality of solid state light radiation devices are mounted, the layer of down conversion material being spaced from the plurality of solid state light radiation devices.

27. The lighting device of claim 26, wherein the solid state light radiation devices are light emission diodes.

28. The lighting device of claim 26, wherein the down conversion material is phosphor.

PB_I:\RPI\134USP\PAT02.DOC

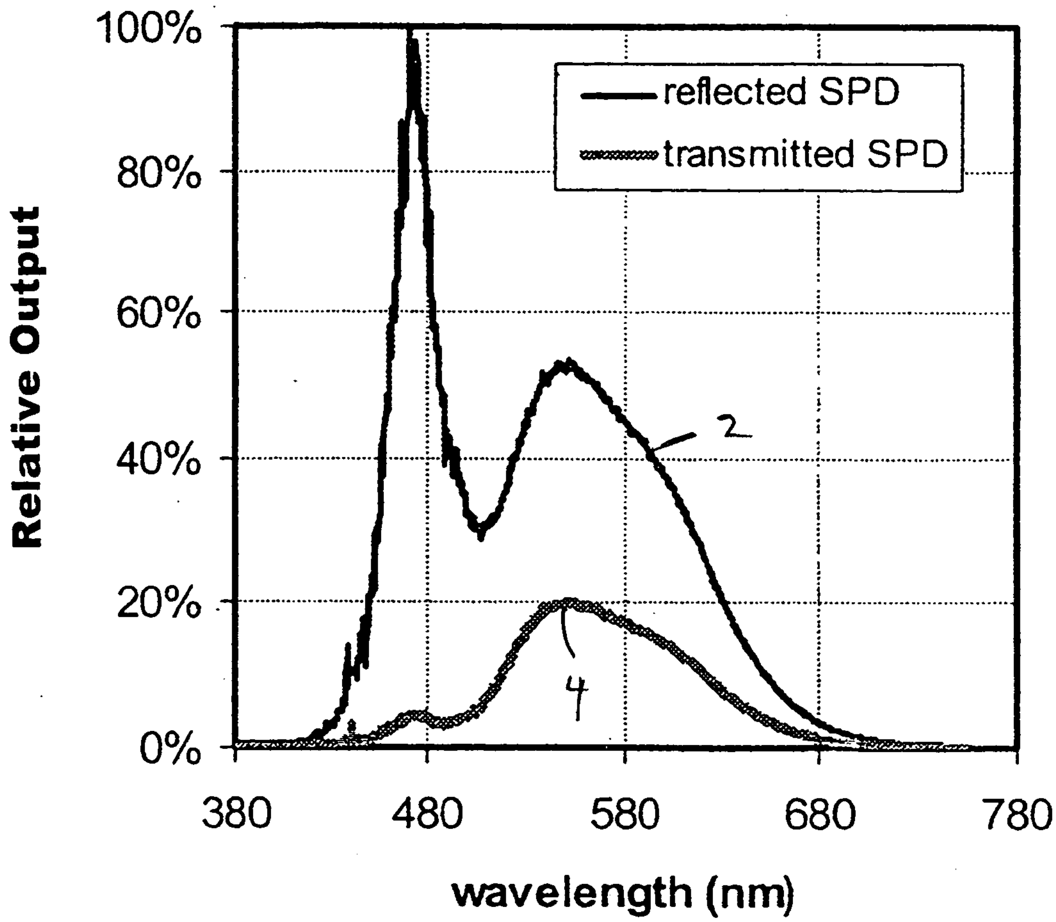

100%
80%
60%
40%
20%
0%
Relative Output
reflected SPD
transmitted SPD
2
4
380
480
580
680
780
wavelength (nm)

Fig. 1

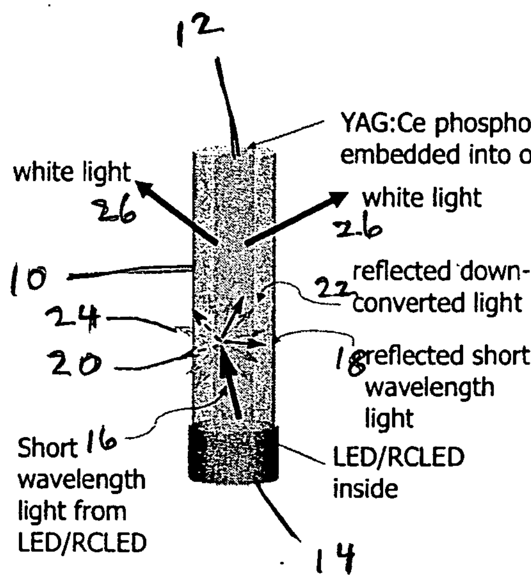

12
YAG:Ce phosphor layer embedded into optics
white light
26
white light
26
10
reflected down-converted light
22
24
20
18
reflected short wavelength light
Short wavelength light from LED/RCLED
16
LED/RCLED inside
14

Fig. 2.

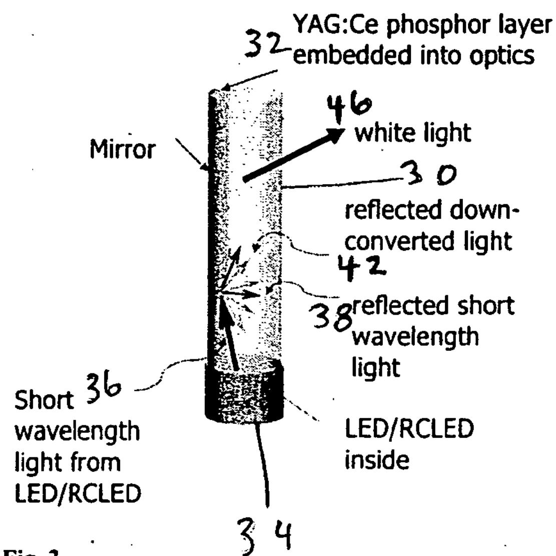

32
YAG:Ce phosphor layer embedded into optics
46
white light
Mirror
30
reflected down-converted light
42
38
reflected short wavelength light
Short 36 wavelength light from LED/RCLED
LED/RCLED inside
34

Fig. 3.

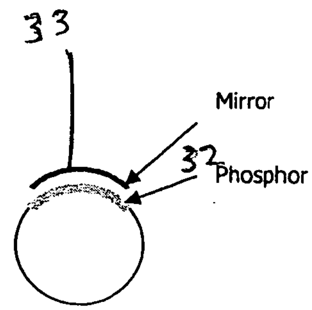

33
Mirror
32
Phosphor

Fig. 3A

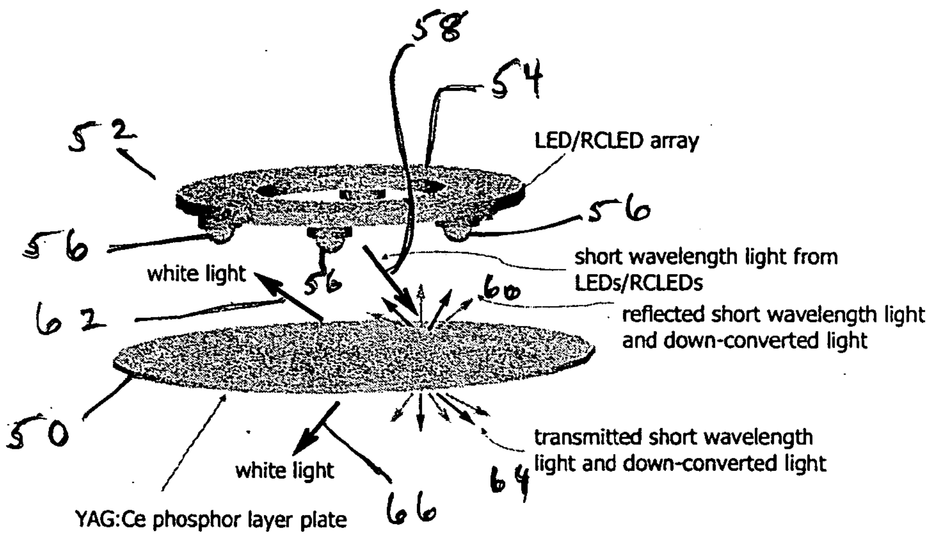

58
54
52
LED/RCLED array
56
56
56
white light
short wavelength light from
LEDs/RCLEDs
60
62
reflected short wavelength light
and down-converted light
50
transmitted short wavelength
light and down-converted light
white light
64
66
YAG:Ce phosphor layer plate

Fig. 4

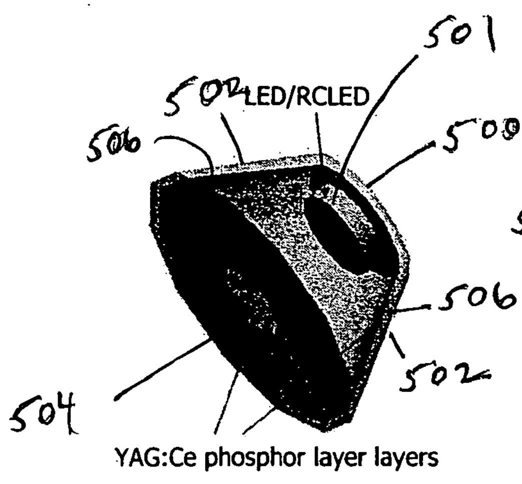

501
502
LED/RCLED
506
500
506
502
504
YAG:Ce phosphor layer layers

Fig. 5A

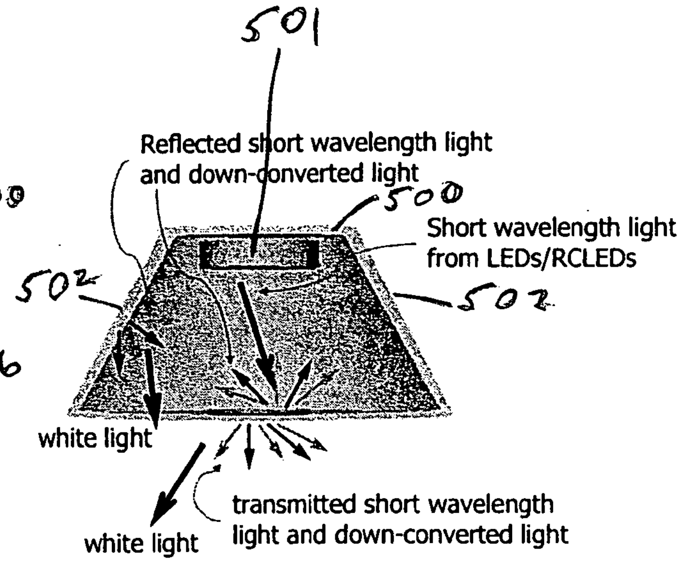

501
Reflected short wavelength light
and down-converted light
500
Short wavelength light
from LEDs/RCLEDs
502
502
white light
transmitted short wavelength
light and down-converted light
white light

Fig. 5B

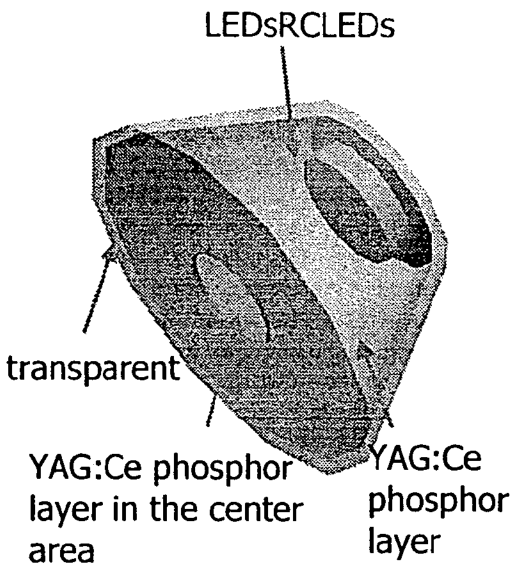

LEDsRCLEDs
transparent
YAG:Ce phosphor layer in the center area
YAG:Ce phosphor layer

Fig. 5C

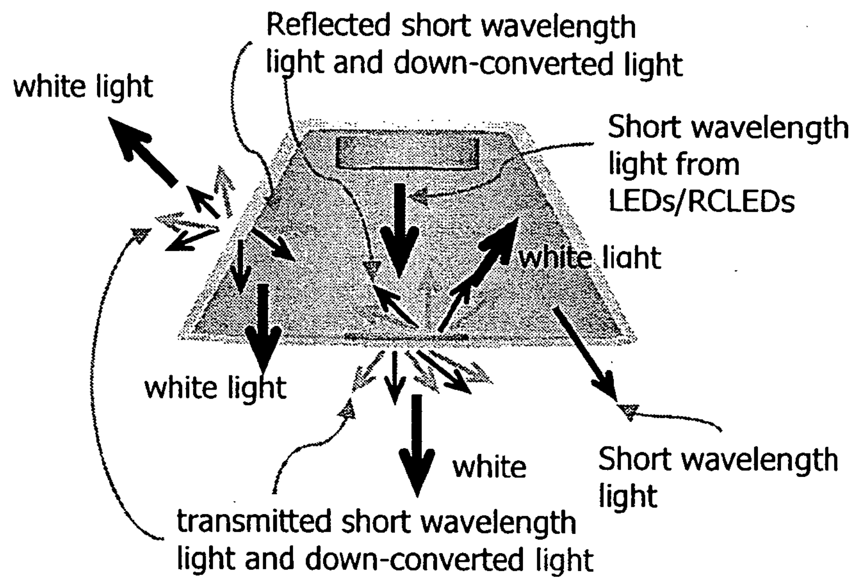

Reflected short wavelength light and down-converted light
white light
Short wavelength light from LEDs/RCLEDs
white light
white light
white
Short wavelength light
transmitted short wavelength light and down-converted light

Fig. 5D

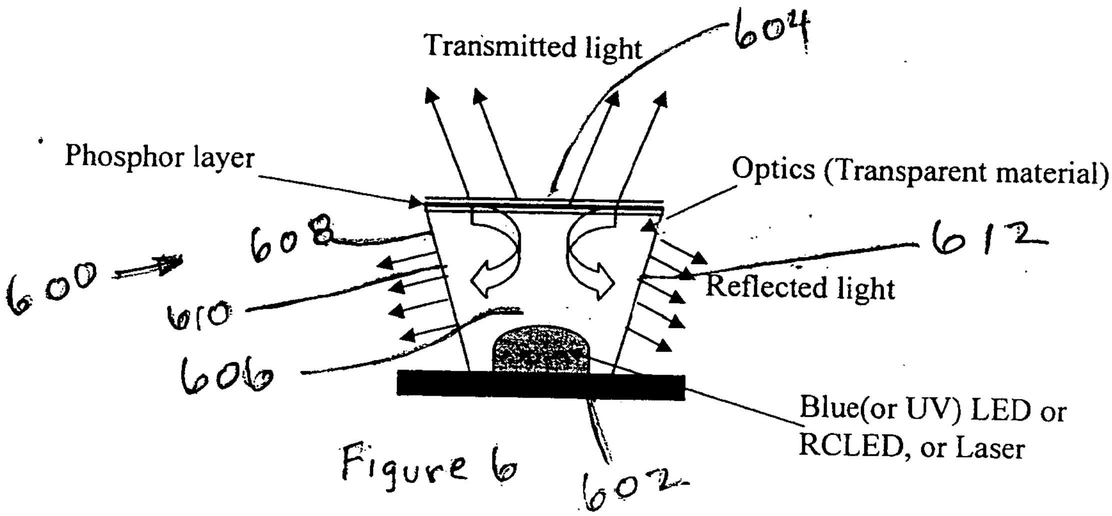


Figure 6

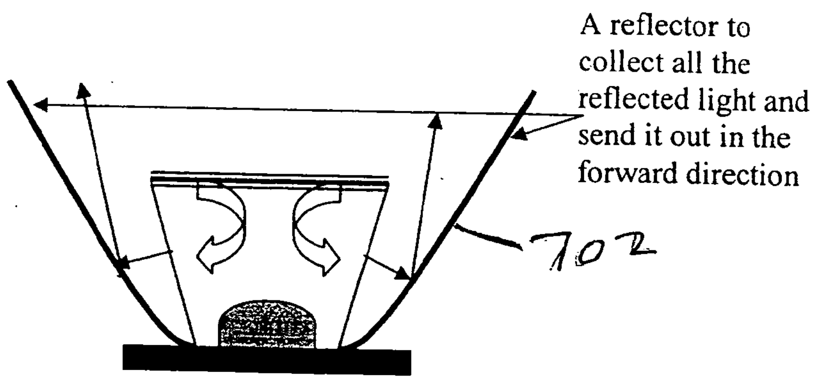
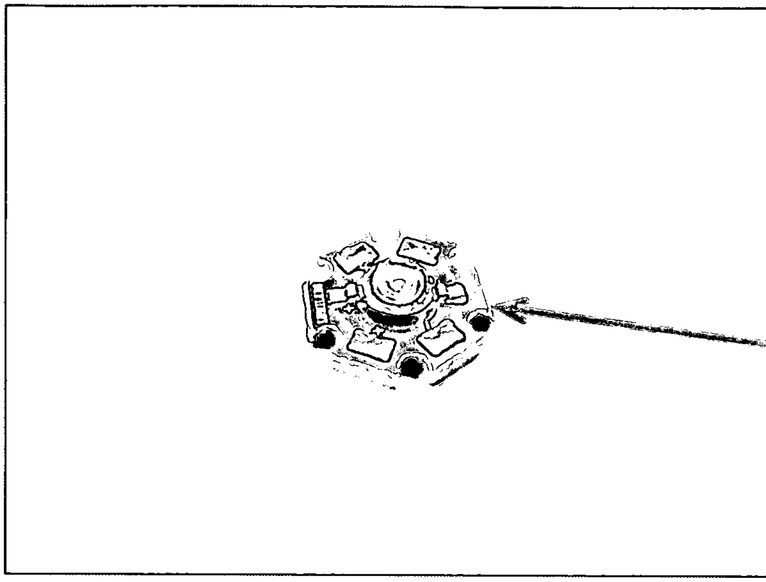
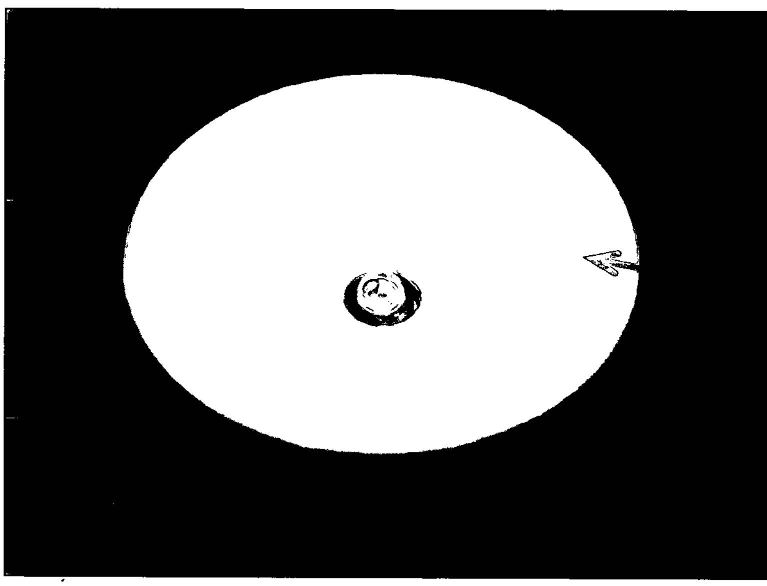


Figure 7



455nm Luxeon
Star LED

Fig. 7A



white reflector
(95% efficiency)
on the LED

Fig. 7B

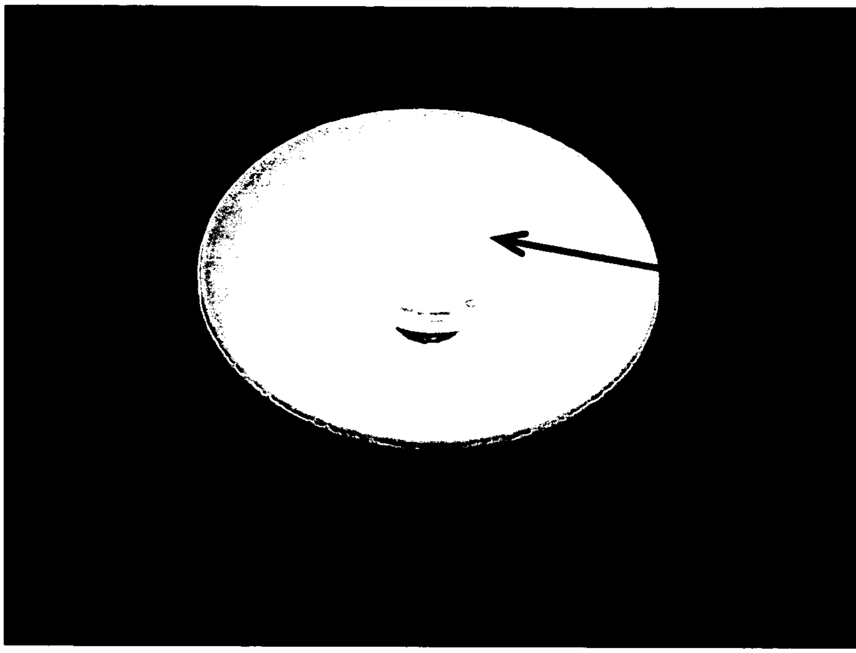


Fig. 7C

Transparent optic with phosphor layer on top

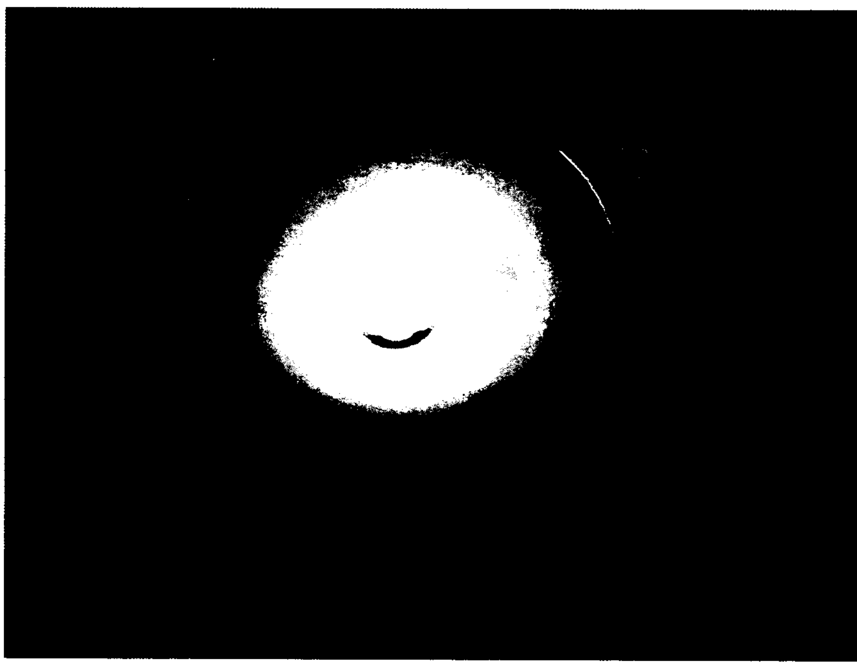


Fig. 7D

SPR package

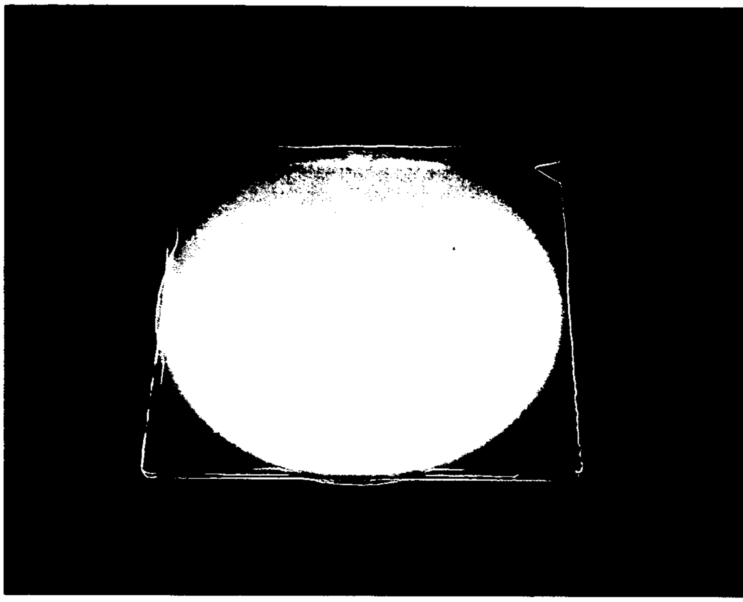


Fig. 7E

High efficiency (91%) diffuse plate on top of SPR package to achieve better color uniformity

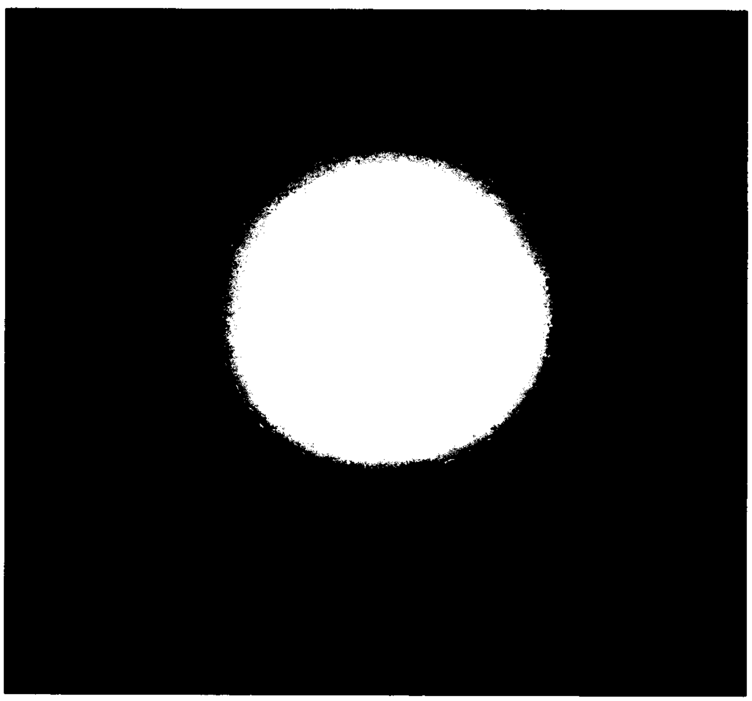


Fig. 7F

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THERE IS NO FIGURE 8

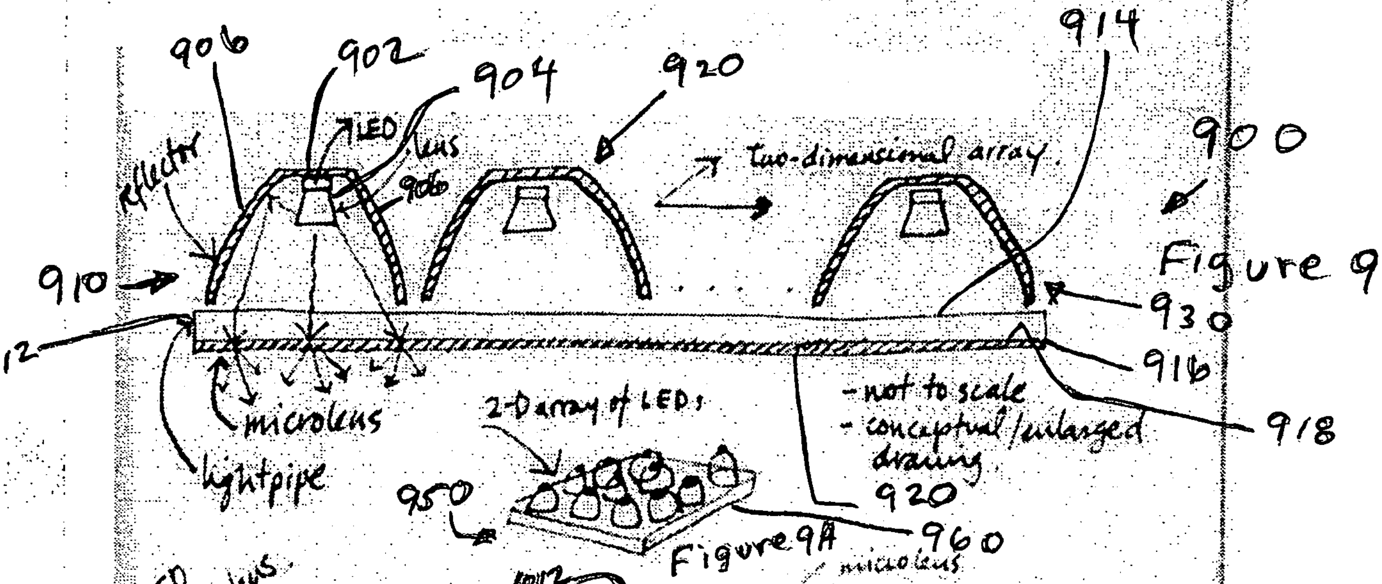

Figure 9

Figure 9A

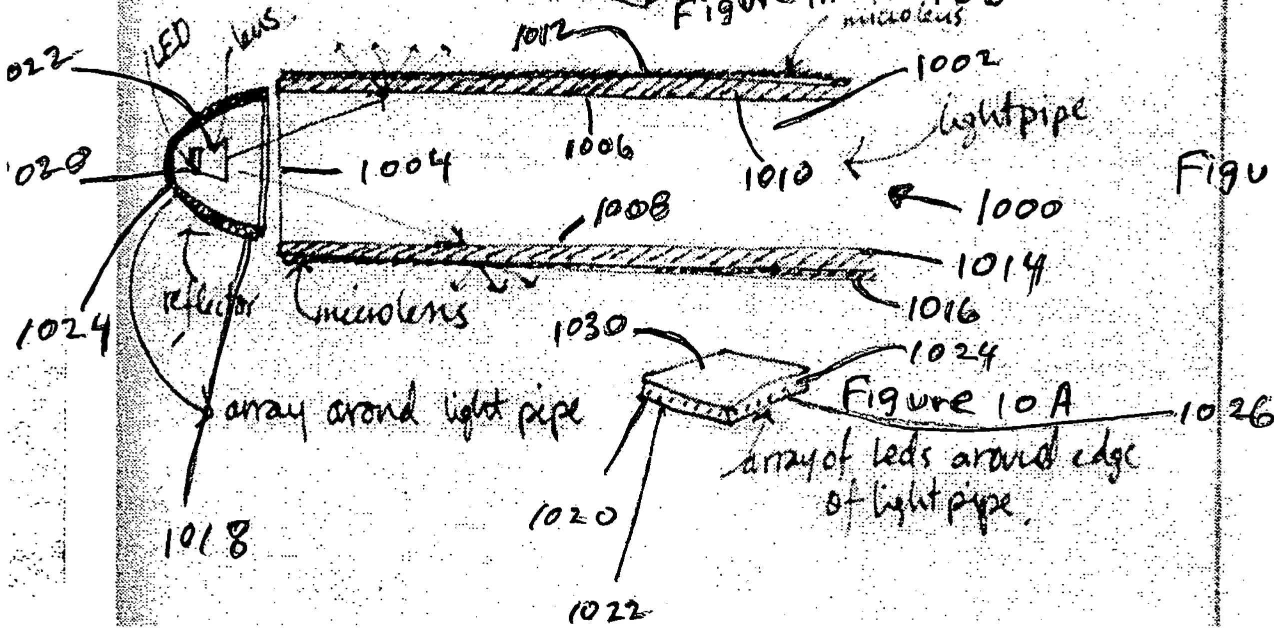

Figure 10

Figure 10A

HIGH EFFICIENCY LIGHT SOURCE USING SOLID-STATE EMITTER AND DOWN-CONVERSION MATERIAL
Narendran et al.
Customer No. 23122; Docket No. RPI-134USP

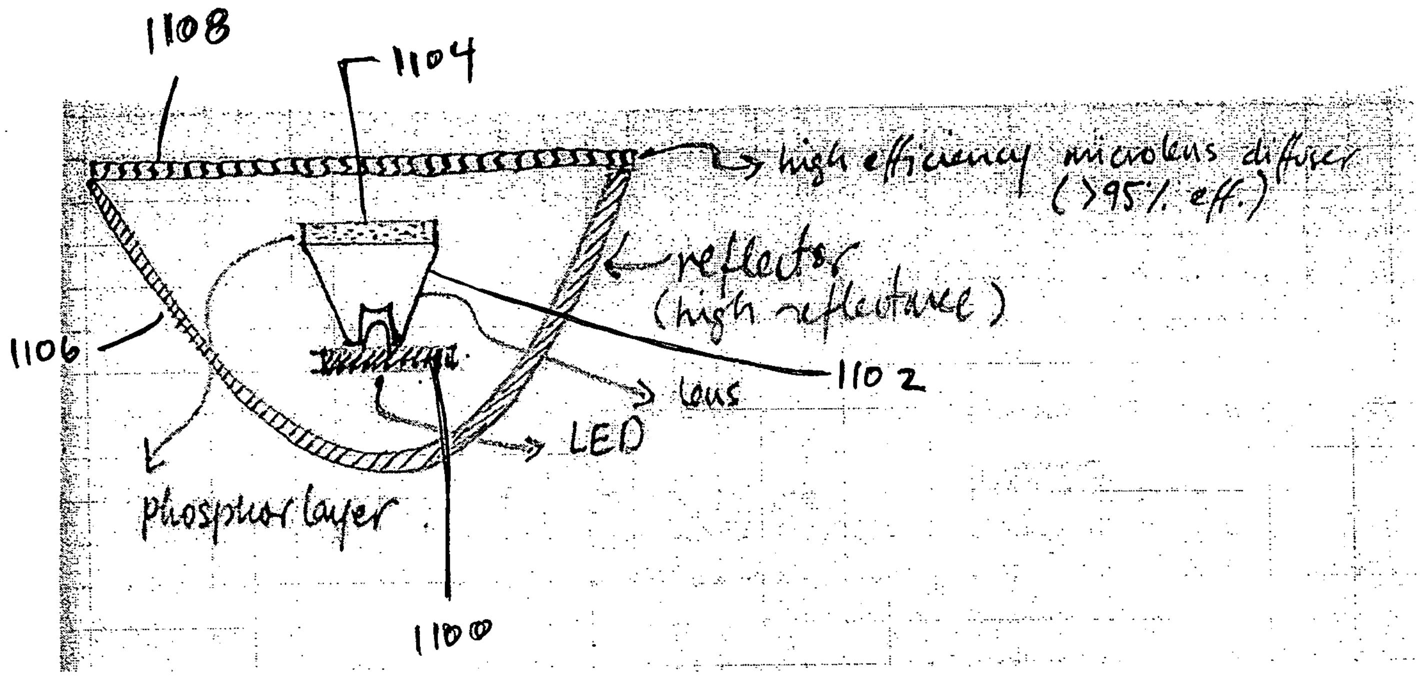
1108
1104
high efficiency microlens diffuser
(>95% eff.)
reflector
(high reflectance)
1106
1102
lens
LED
phosphor layer
1100

Fig. 11

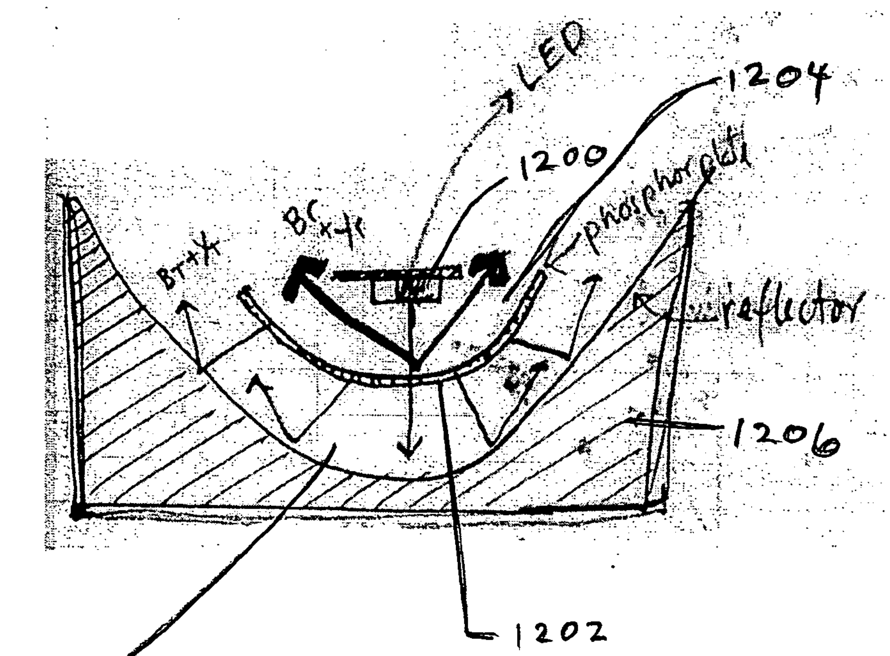

Fig. 12

FIG 13. Experimental setup used for measuring the transmitted and reflected light off the phosphor.

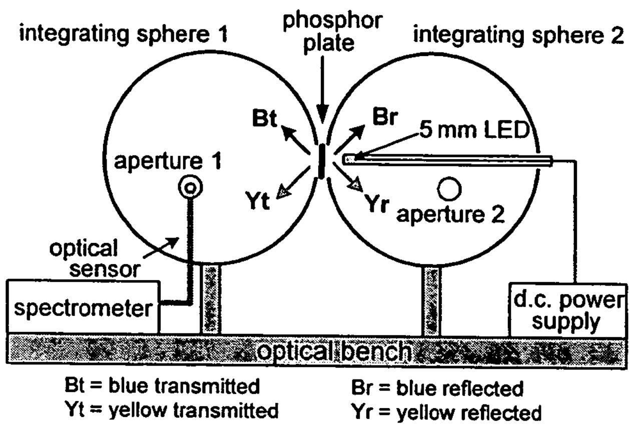

FIG 14. Spectral power distributions for the transmitted and reflected radiations of one phosphor-coated plate ($7 mg/cm^2$).

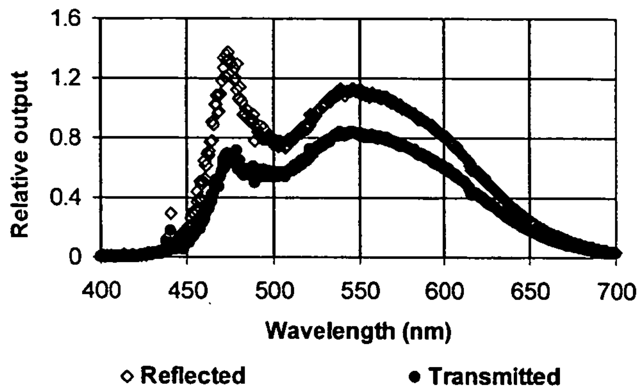

FIG 15. Schematic of the modified white LED package with SPR. The phosphor-coated optic is placed over the high-flux LED. (Not drawn to scale.)

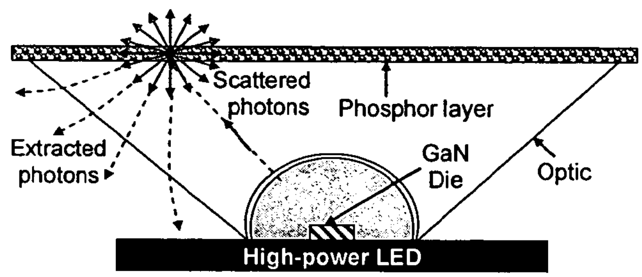

FIG. 16A. Photometric and electrical data for the twelve LEDs.

	Current (mA)	Voltage (V)	Power (W)	Luminous flux (lm)	Efficacy (lm/W)	CIE x	CIE y
SPR #1	700	3.568	2.50	91.0	36.5	0.2878	0.2960
SPR #2	700	3.561	2.49	90.9	36.5	0.2907	0.3097
SPR #3	700	3.586	2.51	92.0	36.6	0.2889	0.2986
SPR #4	700	3.594	2.52	93.2	37.1	0.2900	0.3000
SPR #5	700	3.571	2.50	89.4	35.8	0.2907	0.3107
SPR #6	701	3.539	2.48	87.9	35.5	0.2893	0.2984
Typical #1	645	3.891	2.51	58.3	23.2	0.3198	0.3335
Typical #2	665	3.759	2.50	55.8	22.3	0.3217	0.3336
Typical #3	655	3.818	2.50	54.3	21.7	0.3156	0.3243
Typical #4	640	3.917	2.51	54.8	21.9	0.3158	0.3239
Typical #5	640	3.897	2.49	56.2	22.5	0.3213	0.3357
Typical #6	675	3.716	2.51	59.6	23.8	0.3153	0.3277

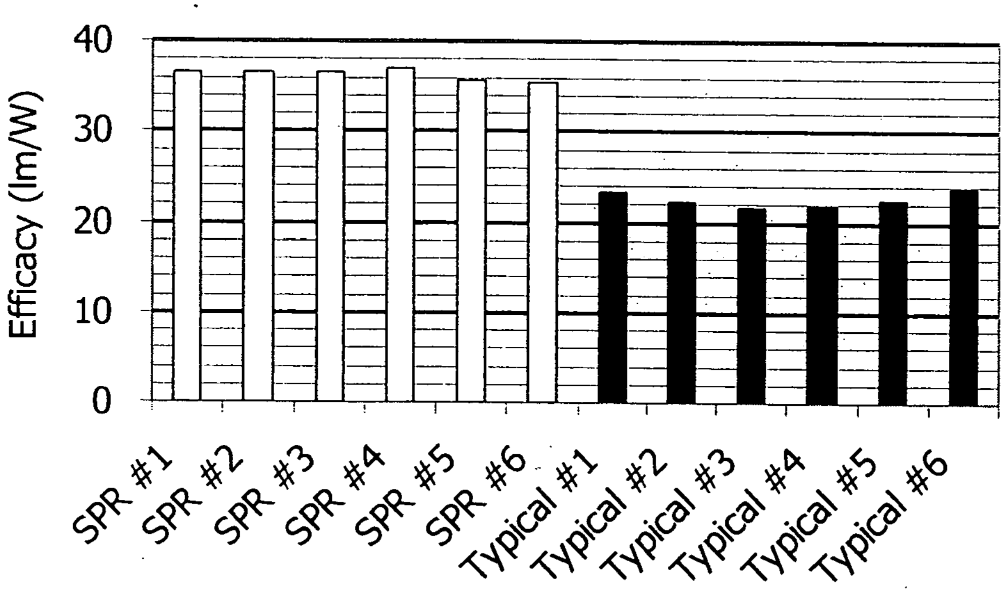
40
30
20
10
0
Efficacy (lm/W)
SPR #1
SPR #2
SPR #3
SPR #4
SPR #5
SPR #6
Typical #1
Typical #2
Typical #3
Typical #4
Typical #5
Typical #6

Fig. 16B

FIG 17. Light output and efficacy of the two types of LED packages as a function of current.